New Mass Spring System formulation to model the behavior of soft tissues

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Karolina Golec (1), Florence Zara (1), Stéphane Nicolle (2), Jean-François Palierne (3), Guillaume Damiand (1)

1. Univ Lyon, Université Lyon 1, CNRS, LIRIS, UMR5205, F-69622, Lyon, France;
2. Univ Lyon, Université Lyon 1, IFSTTAR, LBMC, F-69675 Lyon, France;
3. École Normale Supérieure de Lyon, Laboratoire de Physique, CNRS, UMR5672, Lyon, France

Introduction

Computer-based medicine has been largely developed in recent years for helping surgery, diagnosis and treatment [1]. Unfortunately, from a mechanical standpoint, modeling complex materials such as soft tissues is still a challenge requiring accuracy and possibility of user interaction.
Among computational models (such as Finite Element Method [2], or Position Based Dynamics [3]), we chose the Mass-Spring System (MSS) as model. It offers several advantages, like adaptability and fast computation, while allowing topological modifications (like cutting or piercing) without pre-computations.
In this paper we present a new MSS formulation for soft tissue simulations. The validation of the mechanical response of the model is based on work of Nicolle *et al*. [4] which reported the shear behavior of three vital internal organs (kidney, liver and spleen).
Our method is based on a topological-physical model called *TopoSim* [5,7] which allows to easily implement different physical models and performs fast and accurate modeling of different kinds of tissues. Thanks to this model, we are able to easily adapt the simulation to desired requirements and to perform topological modifications during simulations if necessary.

Method

The environment damping and the tissue's parameters (like Young's modulus, Poisson's ratio, density) are directly connected to the parameters of the MSS. With the formulation proposed in [6] we compute the stiffness (k) of springs. Then, we propose to change the usual springs' force formulation to be able to reproduce the analytical solution reported by Nicolle [4]. Our non-linear formulation of the force of springs (equation 1) allows us to reconstruct the viscous part (the term in first brackets) artificially. We derive it from both: viscous and elastic terms. In the formula c represents the spring damping, n, p are constants and l_0 and l are respectively initial and the current spring length.

$$F=\left(c\cdot\frac{dl}{dt}+k\cdot\left(l-l_0\right)^{1-n}\right)\left(1+\alpha\left|l-l_0\right|^{p-(1-n)}\right) \qquad (1)$$

$$\alpha=\frac{1}{n\cdot l_0}^{p-1}$$

Results

We compare our results obtained for shearing solicitations with the analytical model proposed by Nicolle. We studied the force response of the top layer of the tissue, exactly as performed for the real tissue experiments. We executed the simulation on liver tissue at 0.0151 s-1 strain rate and present results obtained in Fig. 1.

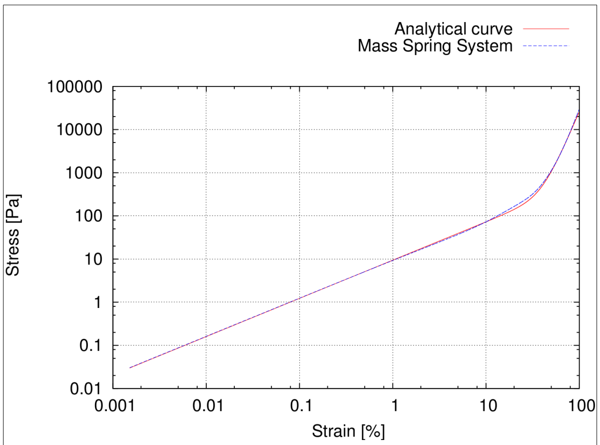

Figure 1: MSS simulation and the analytical curve: comparison (log-log scale)

Discussion

In our simulation experiments we successfully reproduce the non-linear viscoelastic behavior of soft tissues. However, we are working on a generic formulation, which will enforce the correct response in an easy and natural way for different deformation speeds, under other mechanical solicitations. We are working on simulations for other tissues (kidney, liver).

References

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